1. Title

Instructor Notes: Welcome to AWOC winter IC5.1, Potential Vorticity and its Application in Operations. I'm Phil Schumacher.

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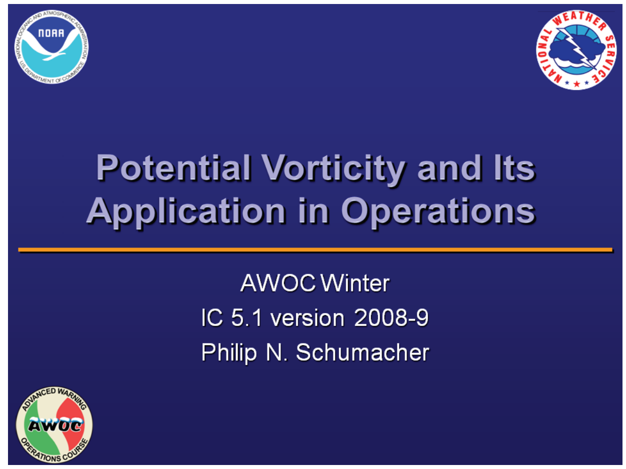

2. Contributors

Instructor Notes: I want to thank the following: Martin Baxter, Central Michigan University Josh Boustead, NWS TOP Ken Harding, NWS TOP

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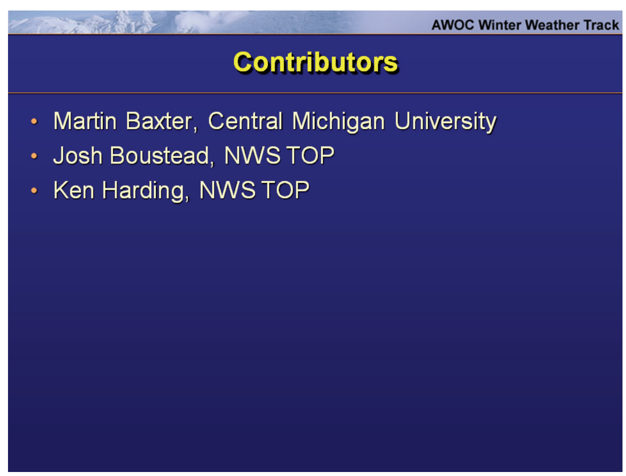

3. Lesson Objectives

Instructor Notes: Be able to list under what two conditions potential vorticity is conserved. Be able to identify where synoptic-scale forcing for lift exists based upon examination of tropopause maps. Be able to list two advantages of using tropopause maps vs examining potential vorticity on pressure levels. Be able to list two advantages of using tropopause maps over Q-vectors analysis

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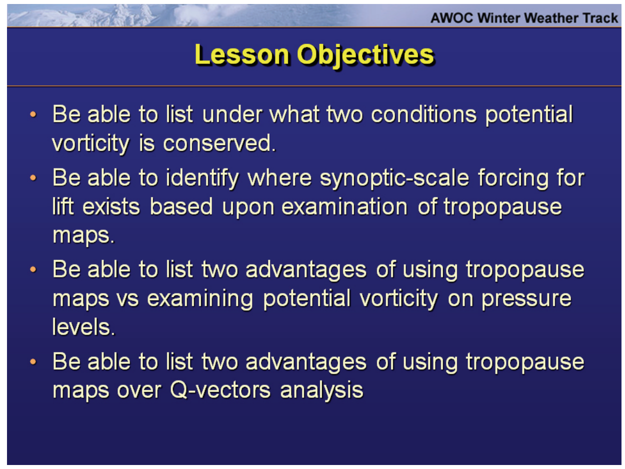

4. Performance Objectives

Instructor Notes: Be able to use tropopause maps to identify the location of troughs, ridges and jet streaks. Be able to develop forecast techniques that allow the display of both upper-level (PV) forcing and low-level (frontal) forcing for the development of intense precipitation.

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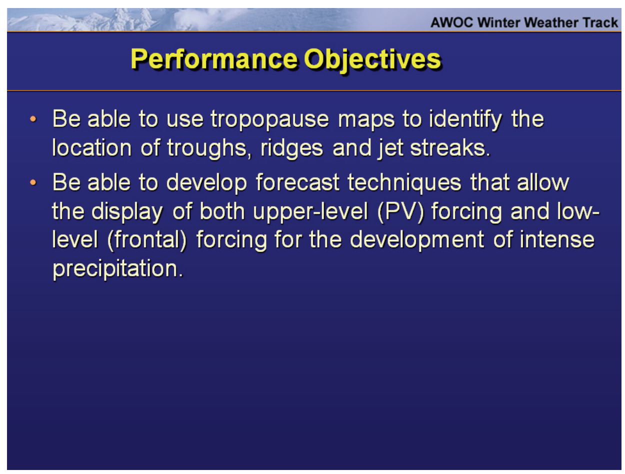

5. What is potential vorticity

Instructor Notes: Potential vorticity is a product of any stably stratified fluid like the atmosphere or the ocean. Within potential vorticity, one has information of the wind field and also of the temperature field. Specifically, potential vorticity is the product of the absolute vorticity on an isentropic surface and the static stability. The power of potential vorticity is that within an adiabatic and frictionless environment potential vorticity is conserved. This means that potential vorticity, or PV, can be followed throughout the atmosphere. This is easiest to do in the upper atmosphere where diabatic heating and friction are both minimized. As we will see later this provides valuable insight because we can more easily envision to movement of short-wave troughs, or positive PV anomalies, through the atmosphere and anticipate their movement. Also, because these anomalies exist at all scales of the atmosphere, we can use high resolution models to observe their movement and follow mesoscale or synoptic scale anomalies. One impact of the conservation of potential vorticity within the atmosphere (when frictionless and adiabatic) is that as a parcel moves from an area of high stability to low stability, it circulation or vorticity will change. In the animation above, the parcel starts in a stable environment. If it is advected into a less stable environment then stability will decrease. In order for stability to be conserved then the cyclonic circulation must increase. If the circulation must increase, then there must be convergence which implies upward vertical motion. So when we look at PV anomalies we are actually looking for times when these anomalies move from high stability to low stability.

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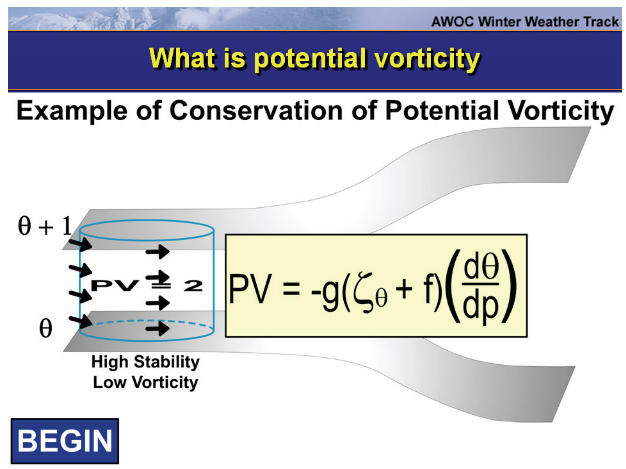

6. PV in the atmosphere

Instructor Notes: Potential vorticity has several characteristics within the atmosphere. In general, potential vorticity within the troposphere is on the order of 0.1 PVU while values within the stratosphere are ~10 PVU. When one goes from the troposphere to the stratosphere, PV values rapidly increase at the tropopause. Within a couple of kilometers near the tropopause, PV values can go from less than 1 PVU to greater than 6 PVU. It should also be noted that PV can reach values greater than 1 PV within the troposphere due to diabatic effects. Be aware that nocturnal inversions and areas with precipitation (latent heating) can result in the production of higher potential vorticity in the mid and lower troposphere. One common example of a diabatically produced PV anomaly is the mesoscale cyclonic vortex (MCV) seen after a long-lived MCS dissipates. However because the tropopause separates potential vorticity values that are 2 orders of magnitude different, we can define the tropopause by potential vorticity instead of lapse rate. Morgan and Nielson-Gammons (1998) proposed a defining a dynamic tropopause as the level where PV is equal to a critical value. They suggested using between 1.5 PVU and 3 PVU. It is common practice to use 1.5 PVU in most instances but values between 0.5 and 2.0 can be used within AWIPS. One can plot pressure on a PV surface and see how the tropopause changes in space and time. One way this is done is to start from the surface and go up through the atmosphere and find the pressure at which PV exceed 1.5

PVU for the last time. By doing this, one eliminates the effects of diabatically produced PV anomalies. In this example, the tropopuase would be defined as 390 mb on the left half of the cross-section and 340 mb on the right half of the cross section. Where the tropopause is lower in the atmosphere (higher pressure) is called a tropopause undulation. This is basically another way to identify troughs within the atmosphere.

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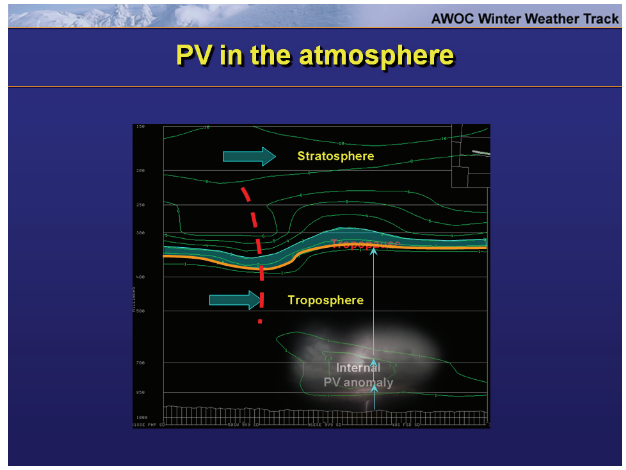

7. Structure of a PV anomaly

Instructor Notes: This graphic from Hirschberg and Fristch (1991) shows common characteristics of tropopause undulations. On a constant pressure surface at or just above the tropopause, in this case at 250 mb, it is a trough in the height field and also a warm anomaly in the temperature field. This is because within the trough, one is in the stratosphere and the lapse rate has switched, i.e. increasing temperature with height, while outside the trough, one is within the troposphere and temperatures have continued to decrease with height. The cross-section (upper right) from 500 – 50 mb, show that there is broad warm advection above the tropopause and between the base of the trough and the top of the ridge. In the lower left, we can see that the static stability within the trough is much higher (more stable) than within the ridge. Finally, looking at PV on a constant pressure surface shows PV is much higher in the trough than it is within the ridge.

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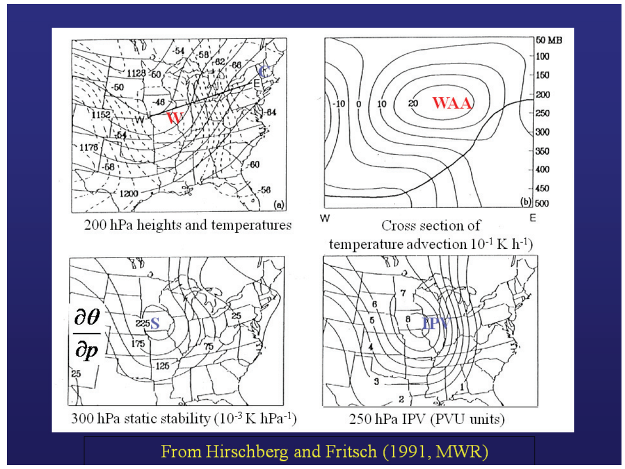

8. Finding tropopause undulations

Instructor Notes: As seen in the previous slide, one can calculate PV on any pressure surface. It can be shown that advection of PV on a pressure surface is synomynous with synoptic scale forcing for ascent. And, because of stability, the advection that occurs when PV is around 1 to 3 PVU is probably more effective at forcing ascent than that occurs when PV is ~10 PVU. Taking a look at this animation and beginning at 450 mb, one starts by seeing two areas where PV exceed 1 PVU – the first over Colorado and the second over western North Dakota. We will concentrate on the anomaly that is located across Colorado. There is a similar analysis at 400 mb although the wave extends into western Kansas. However, at 350 mb, one’s analysis would change. Instead of a gradient in PV across southern Colorado, a large gradient is now located across southern South Dakota. By the time we move up to 300 mb, the gradient is primarily across Minnesota and Iowa and would see very little gradient over Colorado. So depending upon the level one looks at the best forcing for ascent could be either in western Kansas or in central Minnesota. So where is the lift (or is it in both places) and how does one identify both areas? The best way would be to use tropopause maps. One these graphics, the 1.5 PVU surface is highlighted. Let’s plot the pressure of the 1.5 PV surface and see how that looks and if we can identify multiple waves that exist at different levels in the atmosphere in one graphic.

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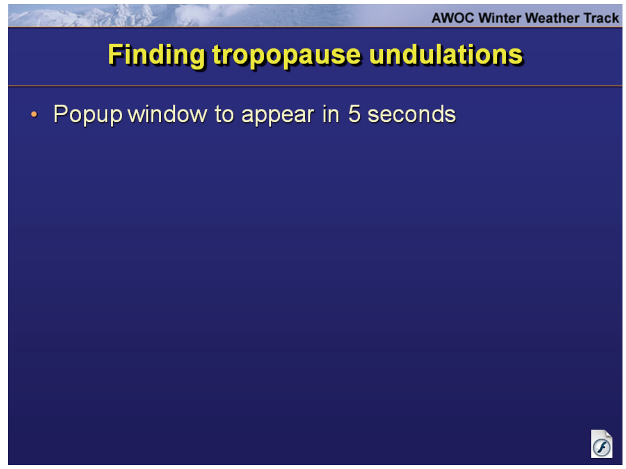

9. Let’s take another look!

Instructor Notes: When we plot pressure on the 1.5 PV surface then we can identify all of the waves we saw at 4 different maps in the previous slide. The main waves over western North Dakota and southern Colorado show up as high pressure and a very tight gradient. However, the more subtle wave in southern South Dakota and central Minnesota are also seen as gradients where there is advection of pressure an the tropopause. So with one map we can identify all the important features that may enhance lift, and snowfall, within our forecast.

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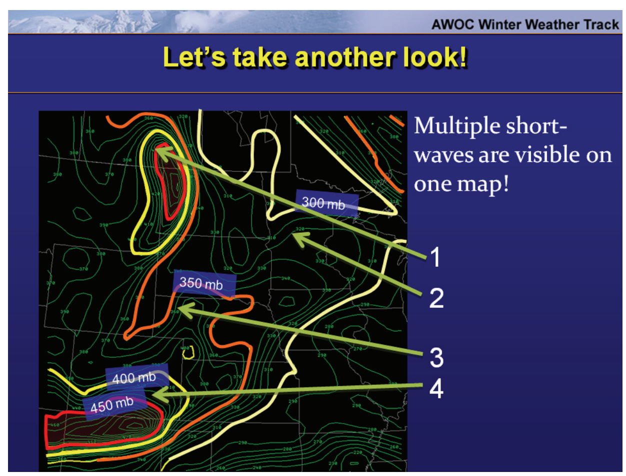

10. PV anomalies related to cyclogenesis

Instructor Notes: Looking three dimensionally, one can see that positive PV anomalies can be associated with both cyclogenesis and with ascent. In the upper left, we can see the PV anomaly approaching a cyclone. As it approaches there is warm air advection aloft (associated with the anomaly and red shading) and near the surface (associated with the developing cyclone. Initially these two areas are disconnected and you have a large area with relatively weak lift. However, as the anomaly, moves over the cyclone (lower two panels) we see the cyclone deepens and we also see that the two areas of warm-air advection are coincident resulting in a coupled circulation and strong lift north of the warm front. When one looks at tropopause maps, one is looking for positive pressure advection. As we saw earlier this positive pressure advection will be in the same area where there is also warm-air advection near the tropopause. Therefore we can generally assume that areas with positive pressure advection on the tropopause will be areas for forcing for ascent due to the approaching tropopause undulation (short-wave).

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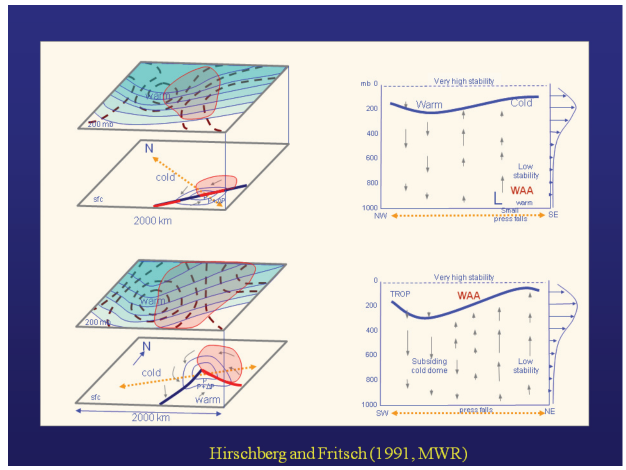

11. Compare to other methods of deducing upper-level forcing for ascent.

Instructor Notes: We have discussed how we can diagnose ascent using tropopause maps but how is this any different or better than other methods – such as Q-vector convergence or examining 500 mb vorticity advection. On this slide we will look at a loop of each of these field with 700 mb frontogenesis (we have assumed that lift will be focused along the 700 mb front in this case) and also display the radar. Before we begin, be aware that 700 mb frontogenesis, 500 mb vorticity and the tropopause pressure were all computed using the 40 km RUC. The Q-vector convergence uses the 80 km RUC. As the loop moves forward let's examine the radar first. Notice a large area precipitation (mostly snow) move from Nebraska into South Dakota and Minnesota. As the loop continues, we see that showers begin to develop over southwest Nebraska as an area of 700 mb frontogenesis develops from central South Dakota into southwest Nebraska. During the afternoon, an area of snow rapidly develops from north central Nebraska into central and northeast South Dakota. This band of snow brought another 4 to 6 inches to portions of South Dakota. Let's run the loop again and look at the Q-vector convergence. In generally we see there is broad forcing for ascent (Q-vector convergence) that moves from Iowa into Minnesota and also become nearly stationary over central Nebraska into eastern South Dakota. The snow that develops in the afternoon is not accompanied by an increase in Q-vector convergence and there is no evidence that the upper level forcing changes much over this area as this snow band matures. Running the loop again, focus on pressure on the 1.5 PV surface. We can see that a short-wave, identified by a tighter gradient on the tropopause, moves out of northeast Colorado and into Nebraska. As it moves into southwest Nebraska, we see the weak showers develop but as this waves moves north toward South Dakota, we see that the band of snow rapidly develops. Thus we can more easily identify the wave that interacts with the mid-level front to produce a band of moderate to heavy snow. While this wave also is seen on the 500 mb vorticity, this field is very noisy and difficult to discern between different vorticity maxima. This becomes an even larger issue in summer when diabatically produced vorticity maxima develop with the model. So the advantage of using potential vorticity is that more subtle, smaller scale short-waves can be more easily discerned than using Q-vectors analysis which focuses upon forcing for ascent from larger scale waves. This is especially true when deep troughs, such as those over Colorado and North Dakota, exist and act to "hide" the influence of smaller, but potentially important features. However, by using a higher resolution model, we are able to discern both the larger waves and smaller waves when we examine pressure and pressure advection on the dynamic tropopause.

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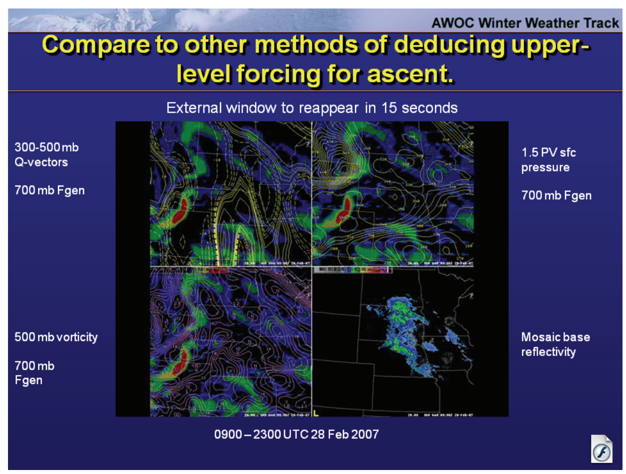

12. Other advantages

Instructor Notes: There is another advantage to using tropopause maps over Q-vector convergence. Q-vectors must computed on a smoothed grid at resolutions greater than 50 km. If the resolution is less than 50 km, then even a smoothed field will have too much energy, or "noise", from mesoscale waves and not provide information on the impact of synoptic scale waves on the forcing for ascent. Above is Q-vector convergence calculated from the 00 h forecast of the RUC at 1800 UTC 28 February 2007. The 80 km calcuation shows a broad area of forcing for ascent over much of the northern Plains with a maximum extending from northern North Dakota into western Kansas. The 40 km version shows this maximum extending from northwest North Dakota into northeast Nebraska with a small area of divergence in central Nebraska. When run in a loop (not shown here), one finds that there is little temporal continuity with many of these "bull's eyes" of convergence and divergence at 40 km and they distract from the larger scale forcing that may be occurring. This can make interpretation of where forcing for ascent is occurring more difficult. However, as we saw on the previous slide, there is much more continuity of the pressure gradients associated with short-wave troughs on the tropopause and we can follow these features as they approach boundaries or other low-level features of interest.

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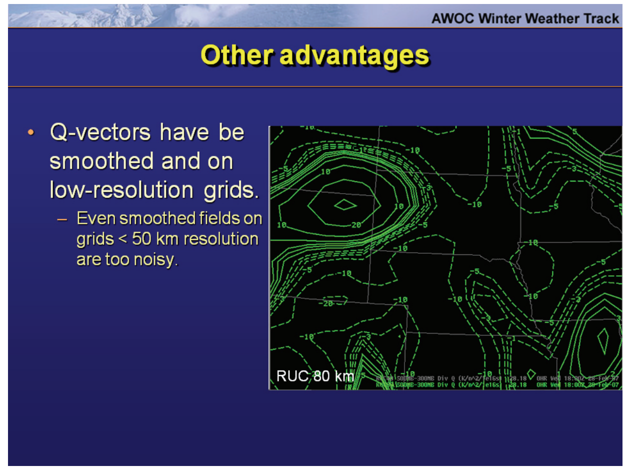

13. Induced flow by PV anomalies

Instructor Notes: So far we have discussed the role of PV anomalies in forcing ascent. However, PV anomalies can also have an influence on the horizontal wind field. In the figure above, there is a positive PV anomaly on the top figure and there is negative PV anomaly on the lower figure. The horizontal wind filed contoured above is that which is derived from the PV anomaly. Notice that despite the fact that the PV anomalies are located above 400 mb, their influence extends all the way to the ground. In the case of the cyclonic anomaly, strong flow, in excess of 12 m/s, extends to the surface while the negative anomaly has winds only less than 10 m/s. The reason for the difference in the strength of the induced flow has to do with the stability of the atmosphere below the anomaly. Notice that in the case of the positive PV anomaly the stability below the anomaly is lower which allows the influence of the wave to more easily reach the ground. In the case of the negative anomaly, the stability is increased below it and the influence rapidly decreases as one approaches the surface.

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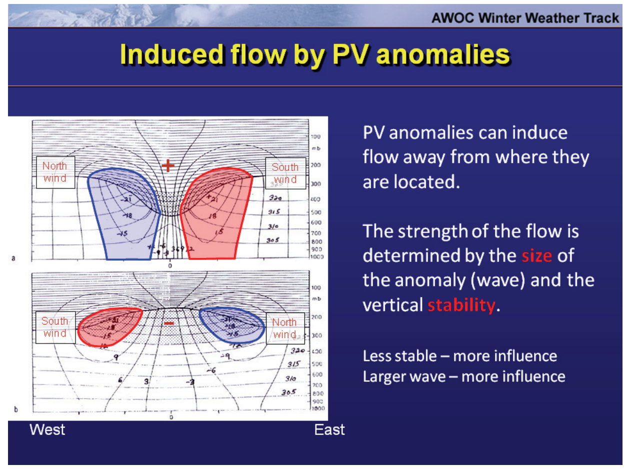

14. One other advantage

Instructor Notes: Another advantage of using PV anomalies is that we can better visualize how deep into the atmosphere it can influence the wind field and enhance vertical motion. As noted in the previous slide, this primarily affected stability. The less stable the atmosphere, the deeper into the atmosphere a wave can influence the wind field. This is way “weaker” waves in summer have a big influence on vertical motion. We will discuss the role of stability more in the next slide. But with PV maps we can also see how deep into the atmosphere a particular wave extends. If we go back to our map from 18Z 27 February 2007, we see 4 waves. Two waves do not extend very far into the troposphere. The wave over southern South Dakota extends down to 380 mb and the wave over central Minnesota only extends down to 330 mb. However, we have two waves that extend into the mid troposphere. Both of them extend below 500 mb. If stability were constant across the entire area, then the waves over North Dakota and Colorado would be most likely influence the wind field and enhance vertical motion into the lower troposphere. However, as we will see on the next slide, it is the combination of stability with the depth of the tropopause undulation that determine the lower tropospheric response.

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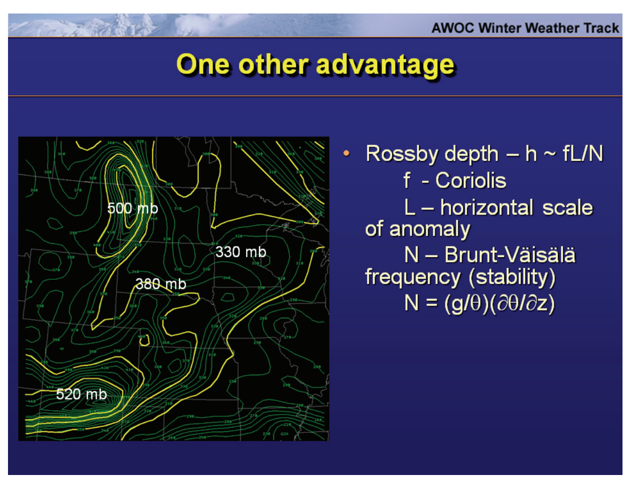

15. Stability and cyclognesis

Instructor Notes: The flash animation that will be loading shortly will show cyclogenesis from a potential vorticity perspective. In the first loop, we examine tropopause pressure, mean sea level pressure, and equivalent potential temperature, Focus on the equivalent potential temperature gradient which extends from western Kansas into Tennessee (and then along the East Coast). An area with higher pressure on the tropopause will move from the northern Rockies into western Kansas. As the pressure gradient moves over the thermal gradient a cyclone develops across western Kansas. This cyclone remains in the ptressure gradient as it moves across the Mississippi River into Tennessee. However, as the low approaches the Appalachians, a new cyclone develops off the East Coast. Both cyclones move northeast, with the western cyclone weakening and the eastern cyclone strengthening. This occurs despite the fact that the pressure gradient ahead of the western wave is stronger than the gradient and pressure advection to the east. To explain what is happening, we need to examine stability. The second loop shows potential temperature on the tropopause, mean sea level pressure and the difference between the boundary layer equivalent potential temperature and the potential temperature on the tropopause. The latter is a simple way to asses the stability on the tropopause. When the two are nearly equal (yellow to red shading) then the atmosphere is nearly unstable and the influence of the PV anomaly can more easily reach the lower troposphere. As you examine this loop, notice that there is lower stability across western Kansas where the cyclone initially develops. The stability decreases across Tennessee and, as the wave approaches that area, the central pressure does decrease 3-5 mb. However, notice the persistent area of low stability off the southeast coast of the United States. This area of low stability occurs because of the presence of the Gulf Stream which results in higher boundary layer equivalent potential temperature. A weak PV anomaly moves from the Gulf of Mexico over this area as cyclogenesis commences off the Carolina coast. As the cyclone develops off the coast, the stability increases near the Appalachians and the primary cyclone fills as it moves west of the Appalachians.

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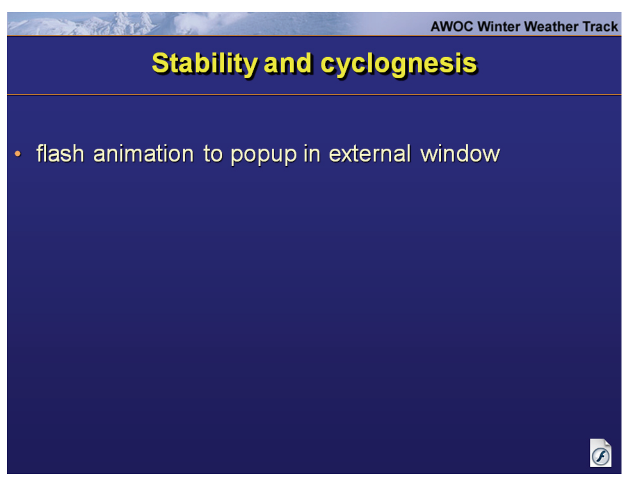

16. Looking at jet streaks

Instructor Notes: There is one caution with using PV dynamics exclusively without considering other conceptual models. That is in the vicinity of jet streaks. As we know from the 4 quad straight jet model, the left exit and right entrance regions of jet streaks are areas favorable for ascent. In the graphic above, we have overlaid 300 mb isotachs with pressure on the 1.5 PV surface. Looking at the left exit region of the jet, we can see a very tight pressure gradient exists with implied strong pressure advection along the tropopause. However, when we examine the right entrance region of the jet, we see that there is very modest gradient – usually on the order of 20-50 mb over 1000 km and without the presence of the isotachs one would probably ignore the weak positive pressure advection that is occurring. Yet in many cases, there will be significant precipitation in this area. Why does the right entrance region of a jet streak not produce large pressure gradients on the tropopause? Recall the PV is the product of stability and absolute vorticity. The “right” (anticyclonic shear) side of the jet streak is a minimum of vorticity while the “left” (cyclonic shear) side of the jet streak is an maximum of vorticity. Also, in many cases, the anticyclonic shear side of the jet is also an area of low stability while the cyclonic shear side of the jet has relatively high stability. Therefore the anticyclonic side of the jet will have a relatively minimum in PV and pressure on the PV surface. Therefore one ends up with a slow increase in pressure as one moves from the right exit region of the jet to the right entrance region of the jet (with most of this increase occurring near the entrance region). Since this is an area of low stability, even the relatively small amount of pressure advection may have a large impact throughout a deep layer of the troposphere. Therefore it is critical when examining PV maps to also include isotachs on the PV surface or at some pressure level near the PV surface. It is also recommended to overlay stability – usually 700 to 500 mb lapse rates. Using both of these calculations with PV surfaces can help you find these more subtle features where they may be relatively weak forcing for ascent from a pressure advection perspective but due to stability may have a large impact on the vertical motion.

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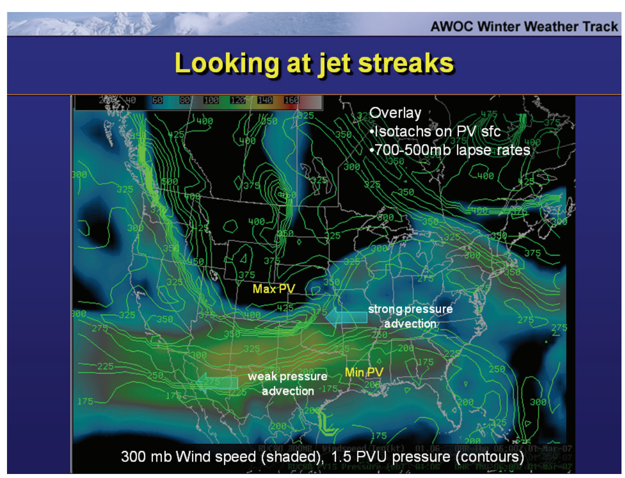

17. IC5.1 interactive quiz

Instructor Notes:

Student Notes:

18. Conclusions

Instructor Notes: Use of tropopause maps provide an easy way to see short-waves at different levels. Depth of wave into troposphere can help determine its ability to interact with mid-level boundaries. Can be used with higher resolution grids than Q-vectors can be applied. Examination of tropopause maps with other features, such as frontogenesis or stability, can identify areas for: Frontal band development Cyclogenesis Convective development Use of PV maps should be coupled with other diagnostics when identifying areas where forcing for ascent may be occurring.

Student Notes: